FINAL REPORT

Machine Learning Approach for Target Selection and Threat Classification of Wide Area Survey Data

SERDP Project MM-1570

DECEMBER 2007

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DoD EPA DOE

Strategic Environmental Research and Development Program

	Report Documentation Page		*Form Approved* *OMB No. 0704-0188*

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1. REPORT DATE **DEC 2007**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**	
4. TITLE AND SUBTITLE **Machine Learning Approach for Target Selection and Threat Classification of Wide Area Survey Data**		5a. CONTRACT NUMBER	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)		5d. PROJECT NUMBER	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Science Applications International Corporation**		8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)	
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited**			
13. SUPPLEMENTARY NOTES **The original document contains color images.**			
14. ABSTRACT			
15. SUBJECT TERMS			

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT **UU**	18. NUMBER OF PAGES **21**	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**			

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

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1.0   Introduction

This project had its genesis in the FY-2007 SERDP Proposal Cycle as proposal 07 MM04-007. The Phase II Defense was briefed to the Scientific Advisory Board on 18 October 2006 and was approved for funding on 15 November following revision to incorporate recommendations of the Advisory Board.

Following the sale of AETC to SAIC in November 2006, the project was awarded to SAIC by HECSA as Contract Number W912HQ-07-C-0023 on 23 April 2007. Because SAIC and VLS were partners in this project, work could not begin until a subcontract was in place with VLS. Because of many miss-steps along the way, the subcontract with VLS was not put in place until September 2007. Therefore the program startup was delayed by a half a year.

The Project Plan calls for applying the techniques developed during the previous projects, UX1322 and UX1455 to the vehicular and airborne Wide Area MTADS surveys of western desert ranges. In project UX-1455 we demonstrated that using machine learning techniques inherent to the Feature Analyst software it is possible to autonomously identify, with high confidence and accuracy, nearly all of the UXO in a survey dataset. Furthermore, we showed the technology could significantly reduce the number of false positives using a two-pass workflow in Feature Analyst with the Target Picker and Target Ranker modules operating (sequentially) separately from each other. The objective of the Target Picker is to independently recognize <u>all</u> anomaly signatures in a dataset that might be True Positives (ordnance). The selected anomalies (referred to in out project as Regions of Interest or ROIs) are passed to the Target Ranker where they are analyzed again to classify the anomalies as ordnance or clutter.

The UXO Toolkit developed for Feature Analyst uses a two-pass target recognition approach. In the first pass the Target Ranker algorithm emphasizes the anomaly shape in the analysis, but also incorporates object size, color, shadow, texture, pattern, spatial association, and signal intensity as feature attributes in the analysis process. During the second pass, the Target Ranker algorithm evaluates each ROI and provides a probability that the ROI is indeed a True Positive (Ordnance) target. During the previous project, this approach was used to analyze the Airborne Survey Data from the 1700-acre Badlands Bombing Range. Following training, the automated analysis requires ~4 hours (using a desktop computer) to process ~10,000 anomalies from the Range. The human analyst required ~75 man hours to accomplish the same task. The automated target picker performance was equivalent to the human-based manual selection, and the Feature Analyst classifier correctly specified 95% of the UXO with 80% fewer false alarms than the human analyst.

Congress authorized a Wide Area Site Assessment Pilot Program to evaluate UXO contamination and identify areas that can be declared ordnance-free on former large ranges. The assessment program included a combination of LIDAR and Orthophotography measurements from high altitude platforms, wide area survey coverage using a helicopter-based magnetometer array and limited transect and blanket area survey coverage using a vehicular-towed magnetometer array. The surveys of interest included the Pueblo Precision Bombing Range, PBR-2, the Kirtland Ranges N1 and N2, and the Victorville Range.

Project MM-1570 has two objectives:

Objective #1: Analyze and classify all magnetic and surface anomalies from all 3 WAA Ranges. Provide a UXO probability for each anomaly;

Objective #2: Accomplish Objective #1 as 4 separate tasks, each being completed and reported before beginning the next.

Task 1: Use mapped data files from common vehicle and airborne survey areas and ground truth from other similar sites, to analyze and rank all targets. (**External Training**)

Task 2: Use the same data and selected ground truth from the WAA datasets to reanalyze and rank all targets. (**Local Training**)

Task 3: Use complete ground truth from dig sites, to reanalyze all airborne datasets and rank all anomalies (**Complete Ground Truth**, with data censored from Bull's Eyes)

Task 4: Use Feature Analyst (UXO Analyst and LIDAR Analyst Utilities) to conduct a **Joint Analysis** of the Orthophotography, LIDAR imagery, and Airborne Magnetometry Imagery datasets. Provide the results in a narrative report.

The Program Office suggested that the project start with datasets from the Pueblo PBR2 Range. These datasets were provided to SAIC on 12 October 2007. **Figure 1** shows the (blue) perimeter outline of the survey area overlaying a topographic map of the Range. Also shown in this image are the blanket coverage areas from the vehicular MTADS as green rectangles and the widely-spaced survey transect tracks of the vehicular array. Magnetic anomalies along the transects are noted with blue, green or yellow symbols. The vehicular blanket survey coverage areas were used in this project, the transect vehicular survey data were not.

Figure 2 shows a closer image of the three upper MTADS blanket survey coverage areas from **Figure 1**. These magnetic dipole anomaly images are superimposed on a high resolution aerial photograph of the area. The purple circle overlays the outer ring of an aiming bull's eye. Also visible are partial remnants of some of the inner circles in the bull's eye. As is typical, these are spaced at 100 foot intervals. The left magnetic survey image in Figure 2 shows a relatively higher density of anomalies nearer the center of the bull's eye. These anomalies decrease in density with distance from the center of the aiming circle.

Figure 3 illustrates the extent of the airborne magnetometer survey that was conducted. Because of the rough and uneven terrain in the northwest quadrant of the planned survey area, it was not mapped. The images in **Figure 3** are shown as Analytic Signal presentations. The expanded image from the southwest quadrant of the survey shows an additional bull's eye aiming point denoted by relatively high concentration of magnetic anomalies. It is also apparent that a fence line and/or a road crosses east-to-west just north of the bull's eye. Data were not provided to SAIC as images. We requested that only minimally processed sensor data be provided to us. This is usually referred to as pre-processed data, which consists of removing data from sensor platform turns and areas without RTK GPS coverage or areas where the helicopter altitude was too high to provide useful information. We describe below the form of data that was actually provided.

Figure 1. Image of the survey area of PBR2. The perimeter is shown in blue. The 10 blanket MTADS vehicular survey areas appear as green rectangles. The transect surveys are shown as green (course-over-ground tracks) with magnetic anomalies noted by various symbols.
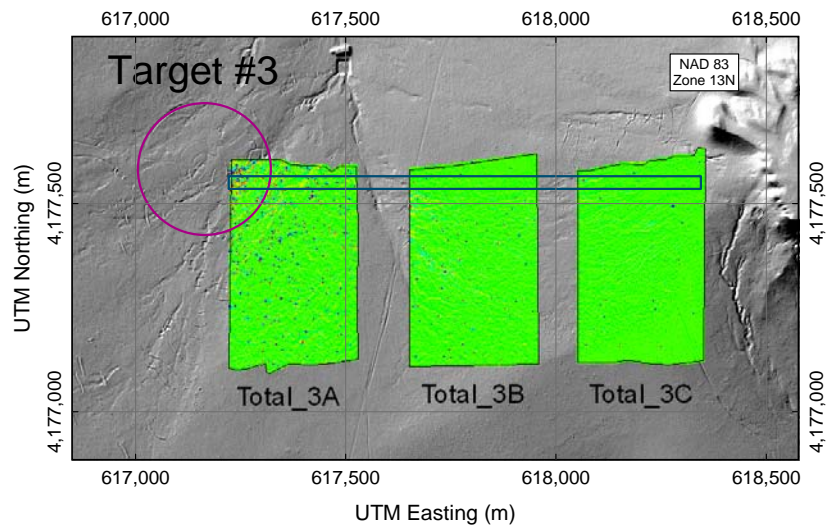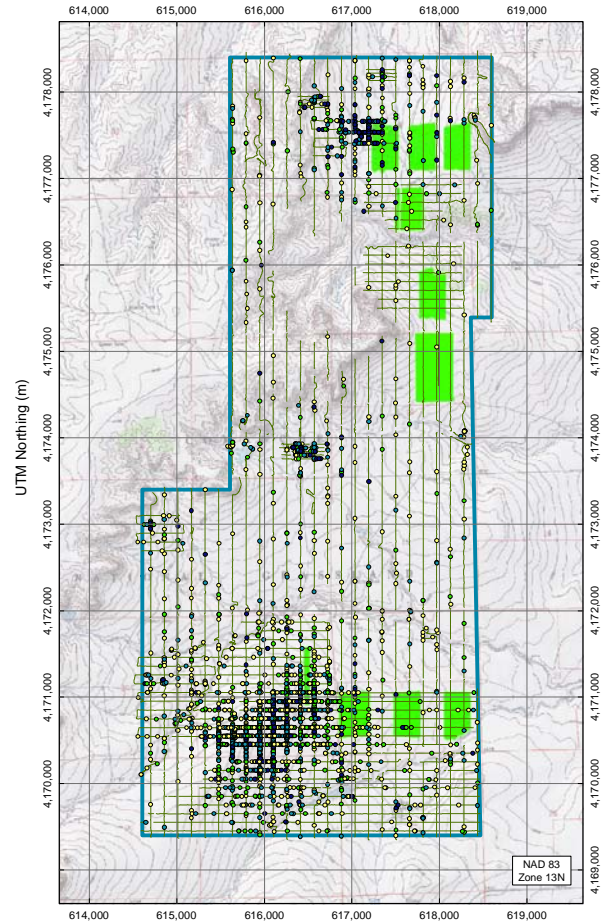
Figure 2. This image shows more detail of the three vehicular survey areas shown at the top of Figure 1. Other details are discussed in the text.

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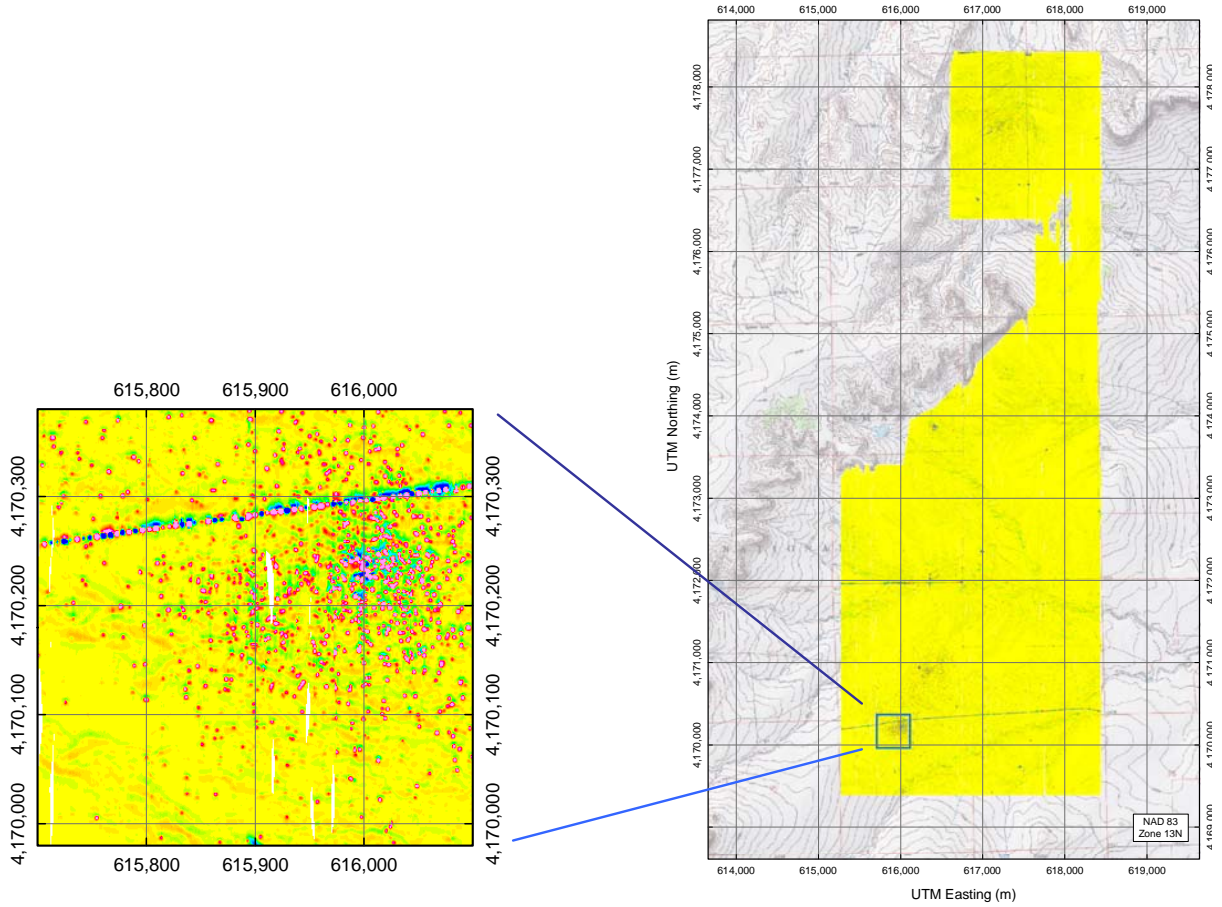
Figure 3. The airborne survey area at PBR-2 is shown in yellow in the right image overlaying a topographic map of the area. A 16 ha area in the southwest quadrant is shown on an expanded scale on the left. This is an Analytic Signal image that shows a concentration of targets typical of a target bull's eye. Note the fence line slightly north of the bull's eye.

2.0   The PBR-2 Datasets

Both the vehicular and airborne data provided to us had been preprocessed using Geosoft montaj utilities. Both the vehicular and airborne data had non-linear spline filtering applied. This is a down-the-track smoothing filter that removes baseline drifts in the sensor readings (and temporal changes in the Earth's field magnitude). Additionally, the data had been leveled. This process removes offsets in the zero value readings of the sensors in the array. Data taken in turns had also been removed.

The vehicular survey data had additionally been processed by interpolating the data onto a $1/8^{th}$ meter grid.

The airborne data were not interpolated when we received them. Airborne data were provided as a mapped data file. Each individual airborne sensor reading was accompanied by five other values including the GPS clock time of the reading, the X and Y coordinates (UTM in meters),

Height Above Ellipsoid (HAE in meters), and the sensor array altitude above the ground (in meters).

SAIC reprocessed both the vehicular and airborne datasets using Geosoft montaj utilities. The interpolated vehicular data were recast in an Analytic Signal format and mapped onto a ¼ meter grid. Digital images were provided to VLS at several different (described below) presentation scales.

The Airborne data were recast in an Analytic Signal format and mapped onto a ½ meter grid. Digital images were provided to VLS at several different (described below) presentation scales.

3.0   Ground Truth

We inspected the PBR-2 datasets for data quality and consistency, variations in the level of geological interferences, and the density of anomalies. We examined the Archive Search Information available to us to determine the types of ordnance deployed, the delivery platforms, and the time frames in which the Range was active. We have numerous survey datasets available to us with similar histories to PBR-2 and for which there were extensive dig programs to generate ground truth following the surveys. Both vehicular and airborne surveys are available for the Badlands Bombing Range and the Isleta Pueblo S-1 Range. We have vehicular survey data for the N9 and N10 Ranges on the Laguna Pueblo and the Buckley Bombing Range. Overall, the best match for the PBR-2 Range was determined to be the Buckley Range. This Airborne Impact Range contains predominately M38s, but also contains both smaller ordnance (down to M23s) and larger ordnance (intermediate sized cluster bomb units). In the northeast corner of the Buckley Survey, a 1 hectare area (Sector A5) was analyzed as having nearly 400 targets. All targets in this sector were dug; the results provide the complete ground truth for the dig list. A dipole image presentation of this area is shown in **Figure 4**. SAIC prepared Analytic Signal digital images of Sector A5 in the same
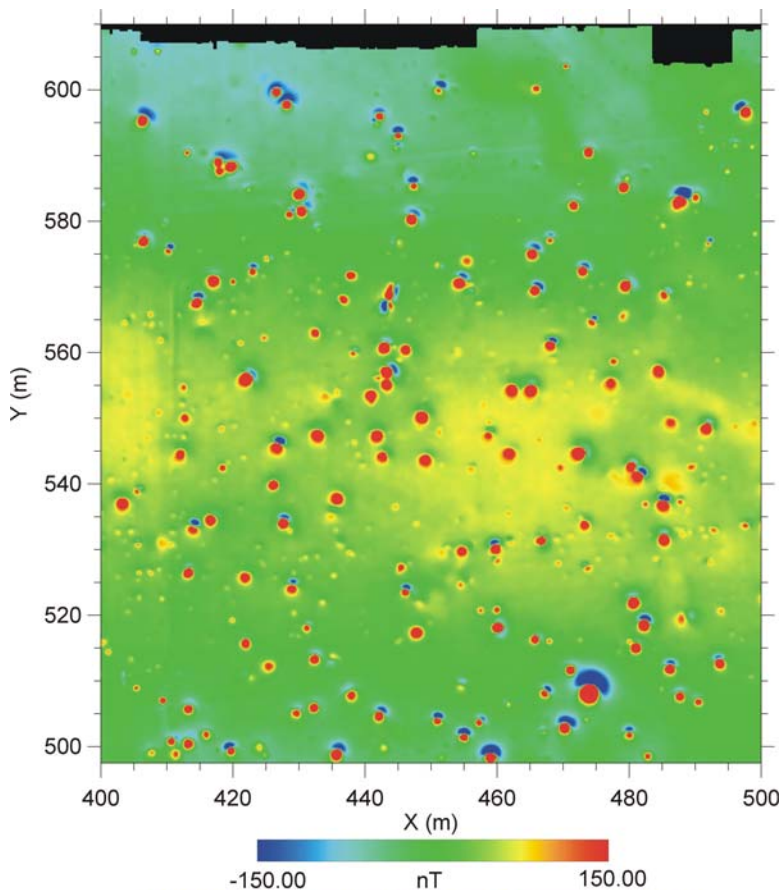

Figure 4. Magnetic anomaly dipole image of Sector A5 on the Buckley Bombing Range.

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presentation scales that were prepared for the vehicular survey areas of PBR-2. These were provided to SAIC along with a suggested list of 12 True Positive and 6 True Negative anomaly examples for training. The extract from the Section A5 dig list that shows the suggested training examples is shown in **Table 1**. The use of this data is described in the next section of this report. Only M38s, 2.25 in Rockets, and the larger Incendiary Cluster Bombs were chosen as True Positives. At this site the ground was particularly hard and many of the M38s were severely deformed (or completely fragmented) on impact. One M38 anomaly was also chosen as a "True Negative" example because its anomaly signature closely resembled a dispersed group of clutter items. Many other ordnance targets from the site were also excluded from the training list because they were much smaller than we considered as typical of the ordnance dropped on PBR2. The effect that this had on the overall training evaluation using the Buckley data is discussed in the next section of this report.

Table 1. Target Report from Buckley Bombing Range, Section A5, Training Examples

True Positive and True Negative Examples for Training for Pueblo Bombing Range #2
True Positive Examples
True Negative Examples

	MTADS ANALYSIS									GROUND TRUTH
Targ. ID	UTM Easting (m)	UTM Northing (m)	Burial Depth (m)	Size (m)	Moment	Incl (deg)	Azi (deg)	Fit Quality	Analyst Comments	TYPE
25	529556.54	4386788.19	0.52	0.156	2.0826	84	90	0.986		100# INERT, M38
168	529607.40	4386761.92	0.29	0.119	0.9128	17	38	0.994		nose of cluster from #150
22	529566.08	4386793.45	0.34	0.128	1.1456	84	96	0.986		100# INERT, M38
14	529572.38	4386767.08	0.40	0.131	1.2418	61	16	0.994		100# INERT, M38
24	529561.88	4386769.35	0.47	0.140	1.4957	86	40	0.998		100# INERT, M38
111	529570.03	4386837.86	0.66	0.197	4.1887	81	90	0.982		100# INERT, M38
26	529553.99	4386787.27	0.57	0.153	1.9503	-7	21	0.976		100# INERT, M38
94	529586.25	4386814.21	0.58	0.139	1.4587	66	52	0.990		100# INERT, M38
145	529625.23	4386790.90	0.35	0.172	2.7932	15	14	0.988		2.25 Rocket
150	529614.06	4386762.15	0.73	0.389	32.3221	77	9	0.995		incendiary cluster bomb
33	529571.21	4386771.87	0.28	0.094	0.4539	34	29	0.997		2.25 Rocket
79	529587.14	4386834.09	0.39	0.161	2.3054	65	48	0.991		100# INERT, M38
4	529575.72	4386791.21	0.95	0.186	3.5401	69	174	0.971	complex signature	100# INERT, M38
102	529562.14	4386838.68	0.10	0.060	0.1155	29	342	0.979		oe scrap
88	529572.74	4386832.67	0.15	0.066	0.1556	1	336	0.989		oe scrap
301	529628.65	4386773.33	1.02	0.166	2.5269	5	69	0.973		hot dirt
13	529577.54	4386783.32	0.14	0.050	0.0702	36	354	0.720		scrap metal
199	529630.92	4386847.51	0.08	0.052	0.0788	11	3	0.990		oe scrap

Because of the late start for this project we have progressed only as far as completing Task 1 for the single site PBR-2. In the remainder of this report we will describe the approach we have taken, the results that were generated and submitted to the Program Office for review, and our plans for completing the project.

4.0   Application of the Feature Analyst Toolkit to the PBR Data

For the completion of Task 1 as stipulated in the Statement of Work, a vehicular target model was developed to apply to new data provided by the Program Office and processed by SAIC. Several tests were conducted using the most effective automated target models previously developed for the Badlands Bombing Range (BBR) project. All models were then applied to the Buckley Bombing Target data in a batch processing mode. The Target Picker was exercised to generate an initial list of potential UXO candidates and the Target Ranker was then used to classify and rank the potential UXO candidates. Using these ranked candidates, combined with the ground truth from the Buckley Impact Range provided by SAIC (Table 1), an accuracy assessment of each model was performed to determine which was the most effective.   The preferred model was then set aside as a template or Target Model File to be further refined and applied later to the Pueblo PBR2 Range.

Before proceeding to the PBR data, it was determined that some existing tools in the Feature Analyst UXO Toolkit could be improved.   In addition several new tools were identified and implemented to improve the results and streamline the overall process. Once the new software improvements were in place, the automated target model was re-applied to the Buckley Bombing Target; this time incorporating the image-wide segmentation tool, which was extensively described earlier.   Upon analyzing the results, it was determined that the use of image-wide segmentation process dramatically improved the accuracy of the results. This improvement in accuracy was based on (1) visible differences in anomaly signatures before and after segmentation and (2) the higher rankings for problematic UXO candidates as compared to the tests run before segmentation. Additionally, a measurable improvement of the true positive ratio in the ROC curve was noted.   These developments are described below in the Section titled Buckley Testing Results.

5.0   Feature Analyst Workflow Used for Task 1

Below is a list of the steps that we took to accomplish the goals for the Task 1 deliverable.

1. Collect and apply previous Target Models from the Badlands Bombing Range to the Buckley Bombing Target data using the provided ground truth.
2. Analyze the results and determine which models were most effective in accurately detecting UXO candidates based on provided ground truth.
3. Develop and refine new and existing software tools (described below) in an effort to improve previous results.
4. Re-apply the models and analyze the results to determine if software refinements had any impact on accuracy.
5. Evaluate the available Feature Analyst parameter settings to refine and improve the results.
6. Run several iterations of the "Classify Shapes by Probability" tool, each time adding additional true positive and true negative examples. The first iteration included a small, subset of the provided True Positive and True Negative examples. In subsequent iterations, the Target Ranker was iteratively retrained by adding equal ratios of True

Positive and True Negative examples from the remaining list of candidates from Table 1 (based on the best-ranked candidates from the previous iteration) until all ground truth examples were included for training the Target Ranker. Each resulting model was analyzed to determine whether it was the most effective in finding and ranking potential UXO candidates. The results are described below.

7. Using the most effective model, generate the final ranked UXO candidate lists for PBR vehicular areas.
8. Clip areas from aerial survey dataset where the aerial image overlaps the vehicular image, then generate ranked UXO candidate lists corresponding to the aerial clips. (NOTE: Area 2A aerial clips were split into two sections to better represent the sections provided in the vehicular data.)

6.0   Software Improvements

In order to generate the best possible results, additional tools were implemented and improvements to existing tools were made.

6.1 Improvements to Existing Tools

- A separate toolbar for the UXO Toolkit with a dropdown menu to allow for easy access to its associated software tools was created and implemented.
- We developed and added the ability to use the "Segment Shapes" tool as an image-wide process that users can apply using batch classification. (Previously, the tool could only be used on individual polygons, which required direct user interaction.)
- We added the ability to combine separate models in Feature Modeler. This is particularly useful for adding new processes (such as image segmentation) to existing models.

6.2 New Tools

- **Import Points Tool** – This tool allows users to import delimited text files containing point locations to be displayed as a feature layer.
- **Label Features Tool** – Given a ground truth layer and results layer, this tool creates a new attribute column called "GrndTruth" and labels individual polygons as true positive, false positive, false negative, or unknown.
- **ROC Curve Generator** – Given labeled results layers, this tool generates associated ROC curves for analysis and evaluation.

7.0   Buckley Testing Results

All target models from the Badlands Bombing Range library were first applied to each of the three palate ranges for the Buckley data. As described in the Workflow Description section, several iterations of Target Ranker were performed to determine whether the accuracy of the target ranker was affected by adding more ground truth points for training. The last model (with all ground truth points included) was determined to have the highest level of accuracy in ranking

potential UXO candidates. The criteria used to determine the level of performance of the Target Ranker were visual analysis, the individual target rankings, and true positive rates based on ROC Curve data. A comparison of the ROC curves produced by the Target Ranker using increasing numbers of training examples is shown in **Figure 5**.
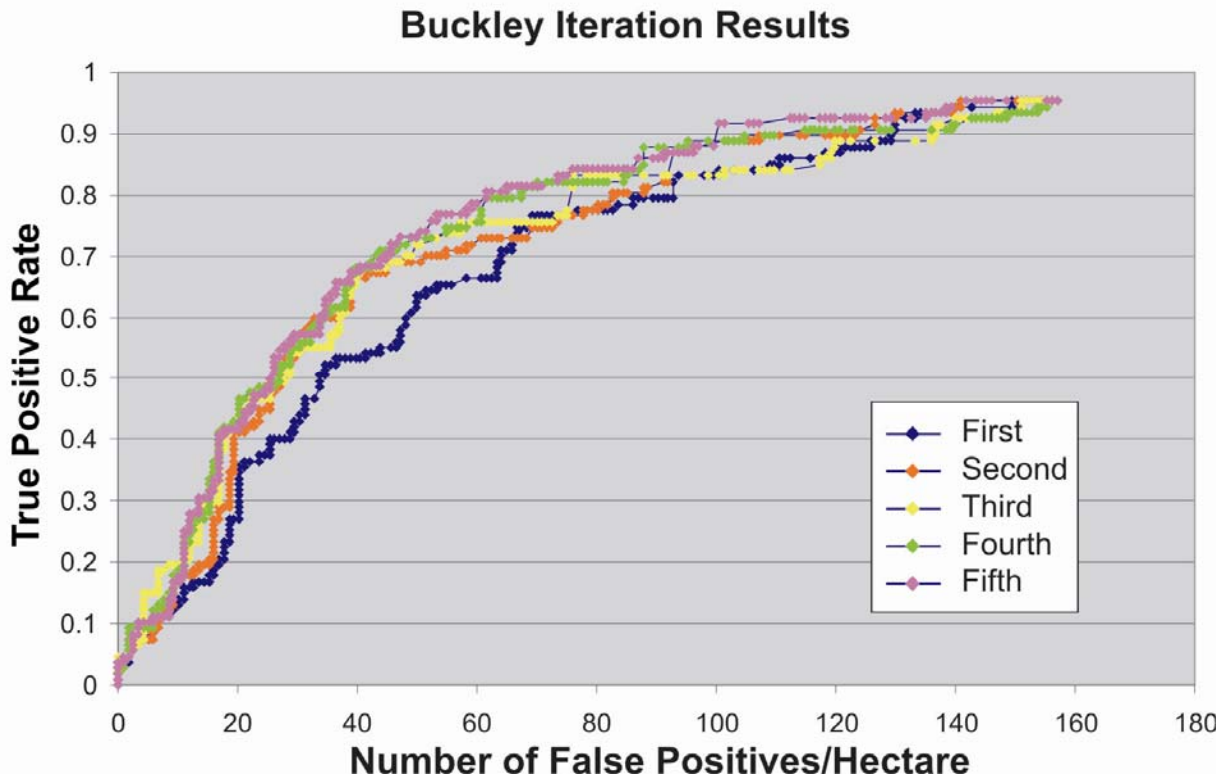

Buckley Iteration Results

Figure 5. ROC curves showing the relative performance of the Target Ranker. With each iteration, the Target Ranker was re-trained using additional ground truth examples. With more ground truth examples the overall accuracy visibly increases. The areas under the ROC curves for the first through fifth iterations were 105.9, 111.9, 112, 115.1 and 116.9 respectively.

Once the preferred target model developed from BBR evaluations was selected (BT2_Section5_300_Revised_Target_Model_Results_Fifth.afe), several additional tests were conducted on each Buckley palette range using a new variation of the Shape Segmentation Tool to further enhance the results. Developing and applying the Segmentation Tool did indeed make significant improvements in the performance of the Target Ranker using the modified ROIs. In several instances, application of the segmentation tool managed to separate True Positive targets examples that were merged with possible non-UXO. In **Figure 6**, we show an example of this process. In this graphic, the bottom layer of the image is a clip from the false-color digitized image (of the Analytic Signal ±300 nT/M palate provided by SAIC from the Buckley A5 dataset). On the next layer up, the ROIs specified by the Target Picker are shown in Light Blue; these were chosen without use of the Segmentation Tool. The very small black diamond in the upper part of the large center blob is the coordinate position of one of the provided True Positive Training Examples.

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Following the implementation of the Segmentation Tool, the ROIs generated by the Target Picker are shown as the light pink features. These form the third layer in the graphic image. Application of the Segmentation Tool has effectively isolated the ROI associated with the True Positive Anomaly Signature. As shown in the image, following application of the Segmentation Tool, this True Positive example is an excellent choice for the learner to apply in the Target Ranking.

A legitimate question remains about the disposition of the anomaly shape immediately below the "True Positive" example in the lower portion of Figure 6. This feature may be a non-ordnance anomaly based upon its oblong shape and dimensions, or it might be two features, which have not been separated at the ±300 nT/m presentation scale used for this analysis. This is typical of the type of feature that ultimately will require a second review following the application of Feature Analyst. Figure 7, which is a dipole presentation of the same clip at a palate scale of ±70 nT, shows that the lower feature is indeed two separate anomalies. Note also that at the presentation scale required to separate these images in Figure 7, that several of the smaller features shown in Figure 6 are lost. Because we use a single digital image palate for the Feature Analyst classification, these smaller (potentially UXO) features must be preserved in the image.

The final results with the Buckley Section A5 Training data and using the automated Segmentation Tool are provided below:

Results for
BT2_Section5_300_Revised_Target_Model_Results_Fifth.afe
Total ROI's: 399
Threshold: 0.30
ROI's above the threshold: 273

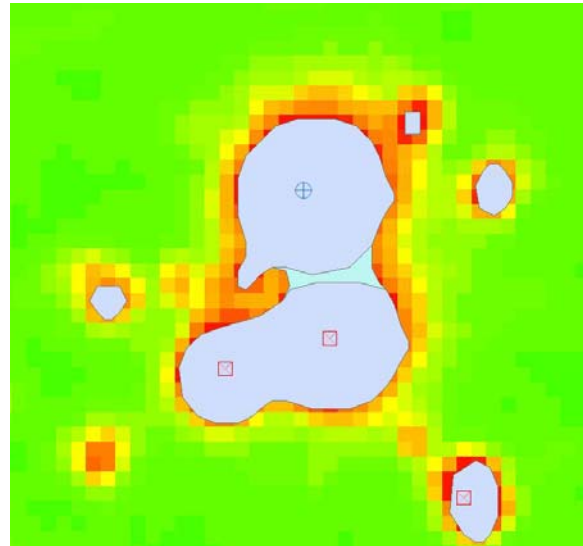**Figure 6. This image shows an example of the effects of application of the segmentation tool. The small diamond in the upper center marks the position of one of the True Positive training examples. The area of the entire image clip is 10 square meters. See the text for details.**
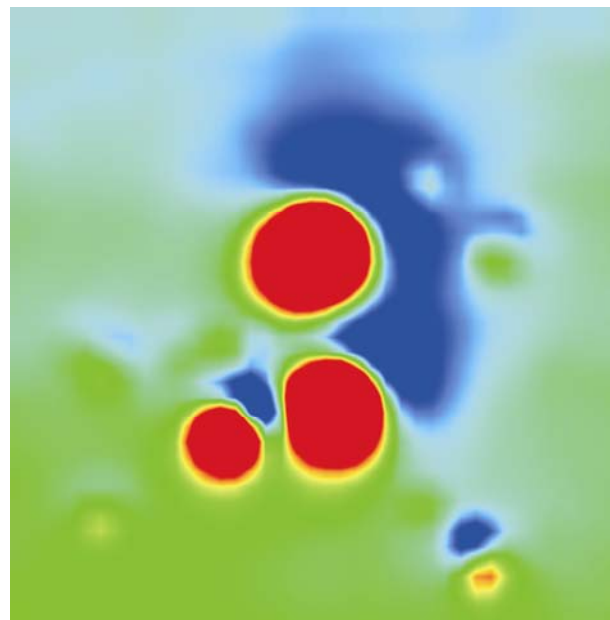

Figure 7. This is a dipole image clip of the same area shown in Figure 6. In this image the palate scale is plus or minus 70 nT.

The Ground Truth for the Buckley Bombing Range Section A5 is shown in an Excel Spreadsheet, which is included in electronic format in the Appendix. In this spreadsheet we have rationalized the Feature Analyst analysis with the original MTADS analysis and the Ground Truth recorded by the dig teams when the targets were excavated. There were 386 targets dug in this survey section. Based upon the diggers declarations there were 321 targets that were intact UXO, UXO components, and UXO "Scrap." Numerous of the diggers declarations were ambiguous, and many UXO declarations were for ordnance items that were smaller (M23s, fuzes, etc) than those that were included in the True Positive training list for use with Feature

Analyst. The Feature Analyst Learner, using the parameters specified above correctly identified 241 UXO items, the Target Picker missed 65 UXO items, and the Classifier misclassified 15 UXO as not-UXO. These results are shown in the ROC curves in **Figure 8**.

The 15 targets that were misclassified were not of concern. They were primarily targets that were smaller than the ordnance included as True Positive examples for training the learner. Also included were a few M38s which were so distorted or fragmented that they appeared to be clutter.

Of the targets missed by the Target Picker, some were smaller than those that the learner was trained to recognize as ordnance. Many others however, were lost in large anomaly shapes that consisted of multiple overlapping anomaly signatures. Some of these clustered ROIs remained in spite of the application of the Segmentation Tool. These "lost" ROIs are worrisome because they contribute both to missed targets and to misclassified ROIs. This issue is discussed further below.
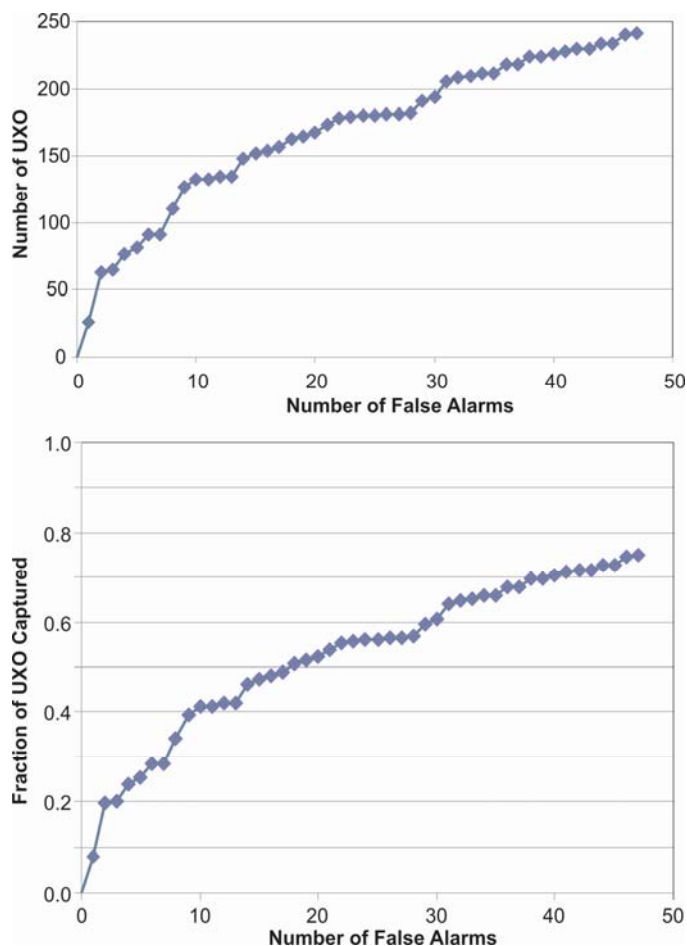

Figure 8. ROC Curves demonstrating the performance of the Feature Analyst Learner on the Buckley Section A5 survey area.

8.0   Palate Analysis Issues

Before beginning discussion of the PBR analysis, we would like to point out and discuss three types of troublesome anomaly signatures that require special attention in the analysis and in reviewing the results. The first of these, are small polygons with weak magnetic signatures that were listed as True Positive training examples in the Buckley training examples. One of these is shown in **Figure 9**. Working with either the ±250 or ±300 nT/m palates, the Target Picker was unable to capture the anomaly This True Positive training example was a 2.25 in rocket. It was relatively deeply buried and had a magnetic moment less than half of the next larger training example. It was intended to represent the smallest likely potential ordnance target. Based upon the smaller True Positive examples to be provided by the Program Office for the PBR2 Task 2 analysis, we may have to either reconsider the palate range for the digital analysis image, or to run the whole process in an additional pass with a more sensitive image scale to separately capture the smallest true ordnance.

A second type of anomaly that creates analysis problems involves True Negative examples that greatly resemble True Positive examples (see **Figure 10**). As a result, these true negative examples are extremely difficult for the Target Ranker to distinguish from true positives and therefore, they are typically ranked very high. Because of the way many M38s either distort or break up on impact, they create distorted signatures that may resemble geological returns, bundles of fence wire, etc. This creates an analysis problem both for this site and for many other sites that contain similar challenges.

Figure 9.   This image shows a 2.5 meter square clip from the Analytic Signal Buckley Image used for training the learner.   The circle marks the position of   Training Target No. 33 in Table 1.
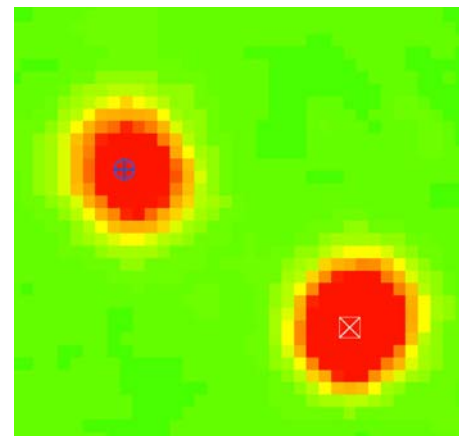
Figure 10.   This 9 X 9 m image clip from the Buckley training site contains two training examples (one positive and one negative) that greatly resemble each other.

Thirdly, some polygons containing multiple overlapping anomaly signatures are extremely difficult or impossible to segment. Occasionally, these polygons such as the one shown in **Figure 11** contain both true positive and true negative ground truth examples. This ±300 nT/m AS image is at too fine a scale to segregate these overlapping anomalies. **Figure 12** shows a dipole image at a 120 nT scale that isolates the overlapping features. In order to isolate these features as an Analytic Signal digital graphic would require a significantly courser palate (perhaps ±450 nT/m).

The examples shown in Figures 9 and 11 show that the +300 nT/m palate chosen for the vehicular analysis has problems with targets both at the largest and smallest ends of the size spectrum. These problems are further exacerbated when analyzing airborne data because the
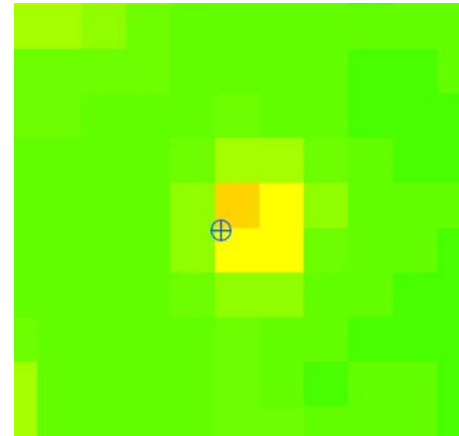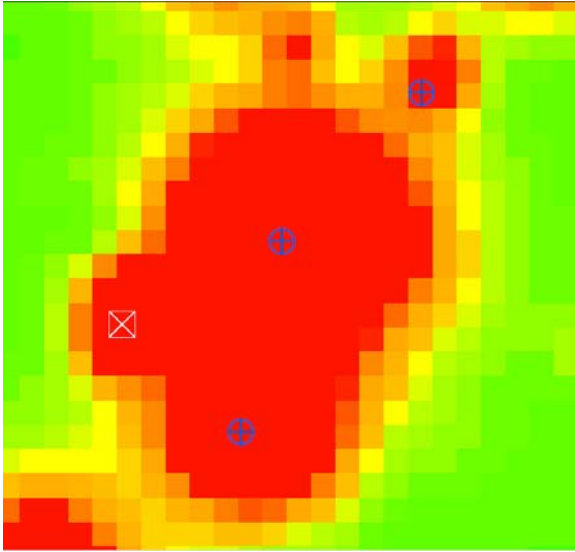
Figure 11. This 6 X 6 m image clip from the Buckley training site contains 4 positive and negative training examples. Three of them cannot be isolated using the Segmentation Tool at this palate scale.
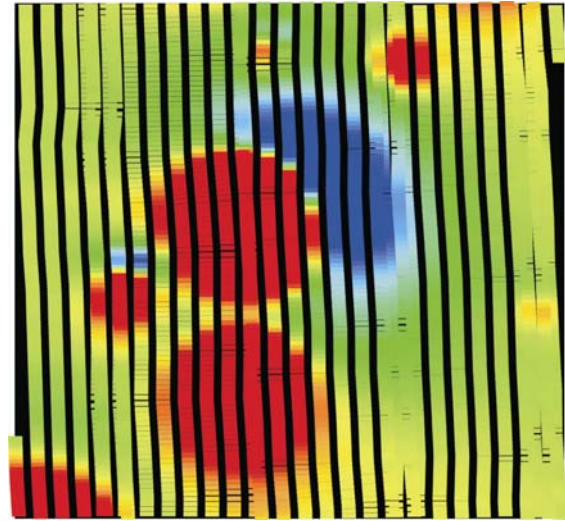

Figure 12. This dipole image clip displayed at a palate scale of plus or minus 120 nT shows approximately the same area as Figure 10. In this image the anomalies area effectively separated.

anomaly footprints are typically much larger than the vehicular-measured anomalies where the sensors are placed much closer to the ground. Depending upon the size range of the True Positive examples provided by the Program Office for PBR2, we will likely come up with an analysis strategy that involves additional analysis passes with the data.

9.0 Analysis of the Pueblo PBR2 Datasets

During the first round of Buckley dataset testing where the shape segmentation tool was not used, it was determined that palate range -250 to 250 yielded the best results with the preferred target model. Still, some troublesome true positive UXO remained ranked lower than all false positive targets (including the candidate Figure 6). When the Shape Segmentation Tool was applied, the best results were produced using the palate range ±300. This likely occurred because the targets were better-define; furthermore, these images contained less of the small clutter areas that could be potentially misclassified. These characteristics were also instrumental in the success of the shape Segmentation Tool and its ability to correctly isolate positive candidates from adjacent merged anomaly signatures. Except for the implementation of the shape segmentation process, no adjustments were made to the learning settings of the original model that we had developed and applied to datasets from the BBR. These settings are provided below:

Learning Settings:

- Bands: (3) BT2_Section5 palette range -300 to 300.tif
- Input Representation: Square 5x5
- Approach: 1
- Aggregation: 5
- Smoothing: Post processing Bezier Smoothing step

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- Histogram Stretch: No
- Rotation: Yes
- Clutter by shape: All options selected

10.0   PBR Analysis Results

Because the best results from the Buckley Range data came from the ±300 nT/m palate range, the final target model was applied to the PBR2 vehicular data with the same range. It was also determined that the most consistent results for the aerial data were generated using the imagery with the palate range ±16 nT/m. With the exception of ground truth data, the same criteria previously used for judging target accuracy on Buckley Range were used for analyzing the PBR datasets. Additionally, given the absence of ground-truth data specifically from this site, target UXO candidates were visually inspected to be sure their associated ranks were consistent across all parts of the survey area.

Finally, after examining the results of the analysis, a cutoff was established for the UXO probability ranking below which we feel that ROIs can be safely declared as non-UXO. Some highly-ranked candidates in the vehicular data are less distinct in the aerial imagery, and some of the smaller polygons in the vehicular examples were simply not present in the airborne data. Even taking into account these differences in available polygon detail and the resulting variation in respective polygon rankings, we have established the same thresholds for the vehicular and airborne surveys. The threshold probability value was set to the rather low value of 0.20. The over-riding factor here was that we were applying ground truth for a site that had a different history than the PBR2 Range. Hopefully, we can be more discriminating when we rerun the training process using real True Positive and True Negative examples recovered from the Range.

A summary of our analyses of the ten separate survey areas is provided in **Table 2**. In the airborne dataset we split the analysis of Area A2 into two sections to conform to the way that the vehicular data were collected. The 21 Excel spreadsheets with entire listings of ROIs and their rankings are provided in electronic format in the Appendix. In all 10 areas of the vehicular survey area the Target Picker specified 4291 ROIs. With the 0.2 probability threshold, we declared 3529 of these as potentially UXO.

The corresponding areas of the airborne survey dataset were analyzed with the Target Picker declaring 991 ROIs. A total of 914 of these were declared as potential UXO based upon the probabilities calculated by the Target Ranker.

The significantly smaller number of ROIs identified from the airborne dataset were the result of the "disappearance" of many of the smaller anomalies in the airborne data. In addition, a significant number of the anomaly signatures merged with each other in the airborne data. The resulting anomaly shapes and magnetic signal intensity distributions led the Target Picker to disregard them in the initial analysis pass. The fact that the learner was also trained only on vehicular data may have played a part in the Target Picker having rejected a large number of anomalies. We had discussed, but did not implement the plan to take a few of the highest ranked (and will-isolated) targets from the vehicular survey analysis and using their corresponding

signatures (as true positives) to train the learner for the airborne survey. These issues will be revisited before we begin the Task 2 analysis.

Table 2. Summary of the vehicular and airborne analysis results for the ten survey areas of PBR2

Vehicular Survey, Analytic Signal Image, Pallate ± 300 nT/m			
Survey Area	**Total Identified ROIs**	**Declaration Threshold Probability**	**Declared UXO**
Area 1A	107	0.20	64
Area 2A	143	0.20	97
Area 3A	672	0.20	564
Area 2A	211	0.20	101
Area 2B	111	0.20	42
Area 3A	1449	0.20	1320
Area 3B	409	0.20	337
Area 3C	167	0.20	110
Area BT4 Center	936	0.20	831
The Simmons Area	86	0.20	63
Total Vehicular Survey Declarations	**4291**		**3529**
Airborne Survey, Analytic Signal Image, Pallate ± 16 nT/m			
Survey Area	**Total Identified ROIs**	**Declaration Threshold Probability**	**Declared UXO**
Area 1A	25	0.20	22
Area 2A, Section 1	38	0.20	37
Area 2A Section 2	25	0.20	11
Area 3A	72	0.20	66
Area 2A	22	0.20	13
Area 2B	42	0.20	24
Area 3A	531	0.20	516
Area 3B	69	0.20	65
Area 3C	25	0.20	24
Area BT4 Center	109	0.20	106
The Simmons Area	33	0.20	30
Total Airborne Survey Declarations	**991**		**914**

11.0   Summary

Based on the results of Task 1, it has been determined that the original BBR target model produced acceptable results on similar but separate datasets and palate ranges. In particular, the Task 1 results confirm that a broader palate range (coarser palate scale) tends to yield the better results.

Before beginning Task 2, we will consider the effect of extending the digital images to even coarser palate scales for both the vehicular and airborne datasets. The goal of this process would be to "unmerge" overlapping anomaly signatures, or sufficiently uncoupling them that the Segmentation Tools could isolate them. A natural consequence of this process is that we will have to implement an additional process using a much finer resolution palate scale for an additional analysis pass with the Learner.

Probably the overall analysis would be done by using the coarser palate to carry out the primary analysis. Following this, we would visually inspect several finer scale images and flag new targets with intensities that raised them above the noise floor sufficiently that the Target Picker could capture them. The goal of this step would be to clearly capture all the known True Positives. These finer-scale targets would have to be flagged and followed through the second pass with both the Target Picker and Target Ranker. The newly Ranked (Flagged) target list would then have to be rationalized by hand with the initial list to produce a single result.

We also established during this year's work that with the addition of an image-wide shape segmentation step, our previous results could be significantly improved while at the same time reducing the amount of required user interaction during the preliminary steps of the analysis. Additionally, the other previously-described software enhancements served to further streamline the process.

For the next task, which will include actual ground truth for the PBR datasets, it will be possible to test and further improve our new and existing tools while at the same time experiment with parameter settings in an effort to reduce more clutter and better rank UXO candidates with an even higher level of confidence.